Electromagnetic Materials Program

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Electromagnetic Materials

Cryo-Systems

Magnetic Materials and Devices

Frequency Agile Materials for Electronics

Advanced Thermoelectric Materials

Single Crystal Growth

Materials for High Density Electronics

High Power Electronic Materials

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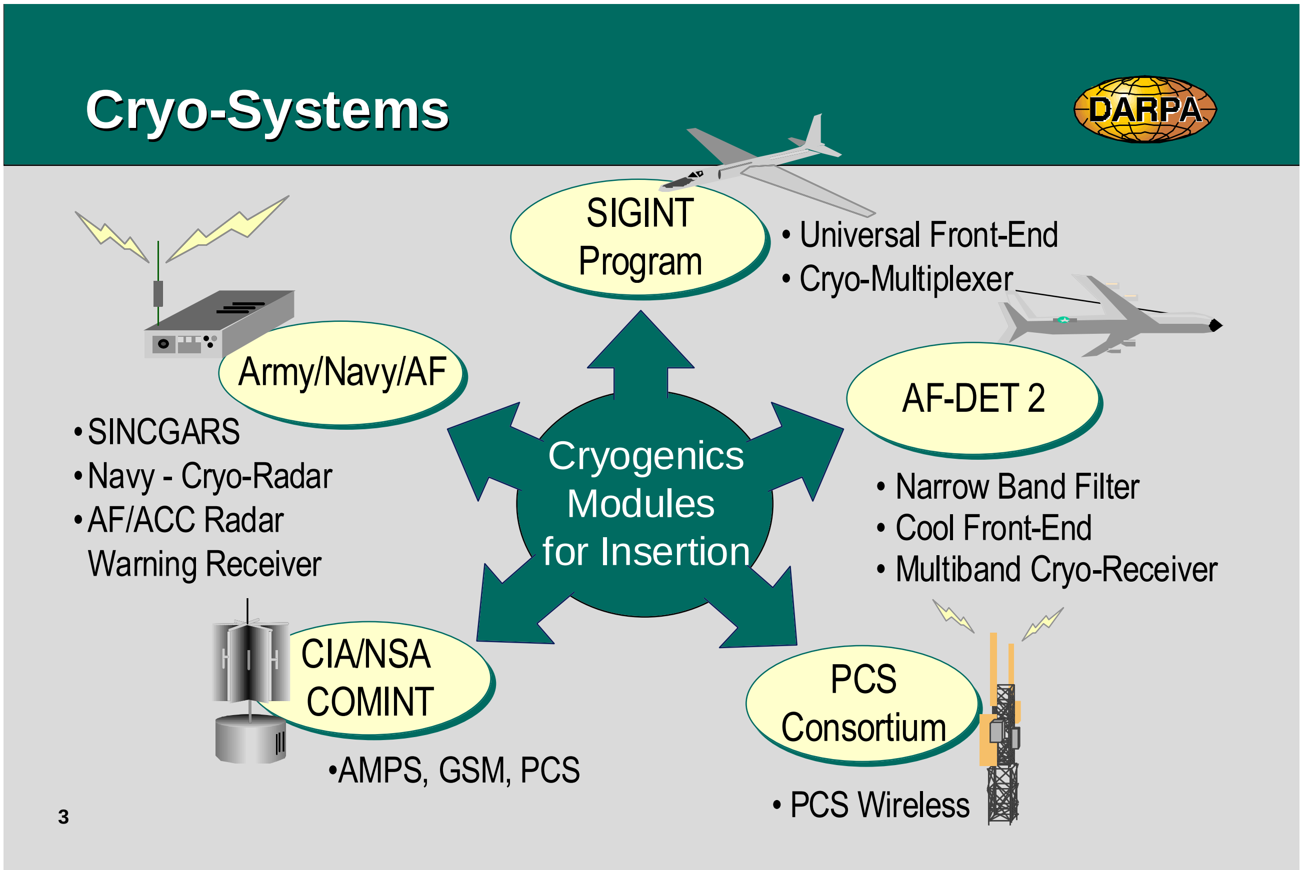
The Electromagnetic Materials Efforts are divided into several programs that are outlined on this slide. These efforts are in functional materials, which is a growing area for DSO. In this presentation I will discuss only the first five programs, which are highlighted in blue. These programs have very far ranging goals as you will see.



The cryo-systems program managed by Frank Patten, DSO, has evolved from the high temperature superconductivity efforts and is focused on the demonstration and insertion of cryogenic technology. There is an emphasis on systems containing very high performance superconducting components. This slide shows several of the areas in which cryogenic systems have been or will be demonstrated for insertions. These systems range from communication receivers through intelligence receivers to very high performance ship defense radars. The elements that provide the enhanced performance are very narrow-band filters, very low phase noise local oscillators and cooled semiconductor low noise amplifiers.

Cryo-System Demonstrations

- Cryo-radar (SPQ-9B) with HTS STALO shows 15db improvement in clutter rejection at NRL Chesapeake Bay Facility
- HTS channelized filters developed for insertion into satellite, airborne and terrestrial communication systems
- Cryocoolers with projected 40,000 hr. maintenance free operation at reduced cost developed

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Several important cryo-systems have been demonstrated. A very low phase noise local oscillator (STALO) utilizing a dielectrically loaded superconducting cavity has been inserted into a prototype SPQ-9B experimental radar at the Naval Research Laboratory’s Chesapeake Bay facility. The performance of this radar against small targets in high clutter has the potential to be improved by up to 15db. In addition to the STALO, many of the conventional radar components have to be upgraded to benefit from the improved noise characteristics. A view of this facility is shown in the slide.

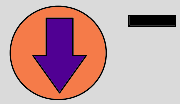
Very high performance superconducting filters, and semiconducting low noise amplifiers have been cryogenically packaged and integrated into a COMINT receiver with significantly improved performance against weak targets in environmentally unfriendly locations. An interior view of this system is shown with integral cooler and dewar. This system can be used in the air and on the ground.

Several cooler manufacturers have significantly improved the reliability of prototype coolers under a DARPA program that had 5 year mean time between failure and $1K cost as the goal. Significant progress toward this goal has been made. The lifetime has been increased by a factor of three, and the cost reduced by a factor of three to five.

Magnetic Material & Devices

Spin Transport Electronics (SpinTronics)

- Takes advantage of the electron spin in addition to the electron charge



- Makes possible a new paradigm of electronic devices
  - Memory
  - Sensors
  - Logic

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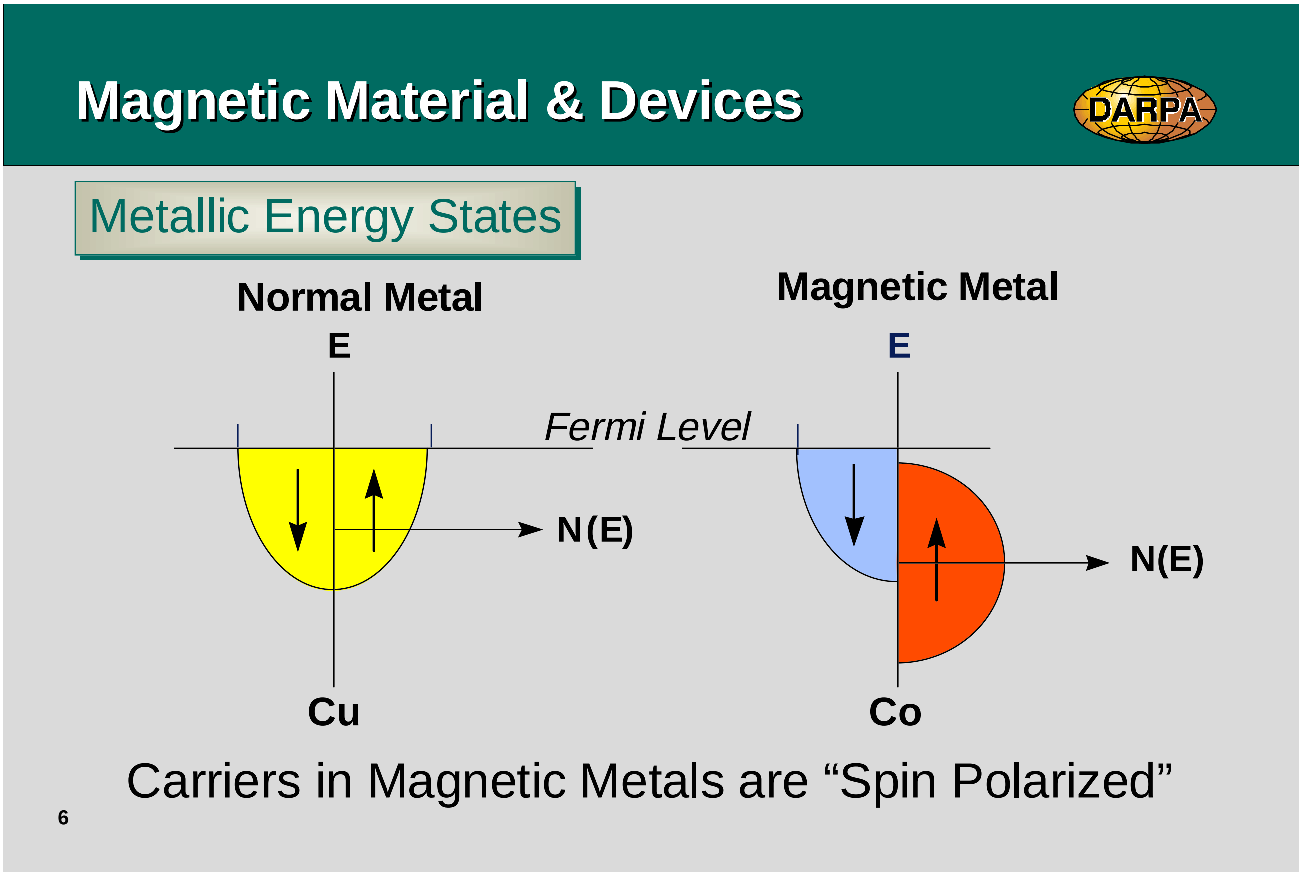
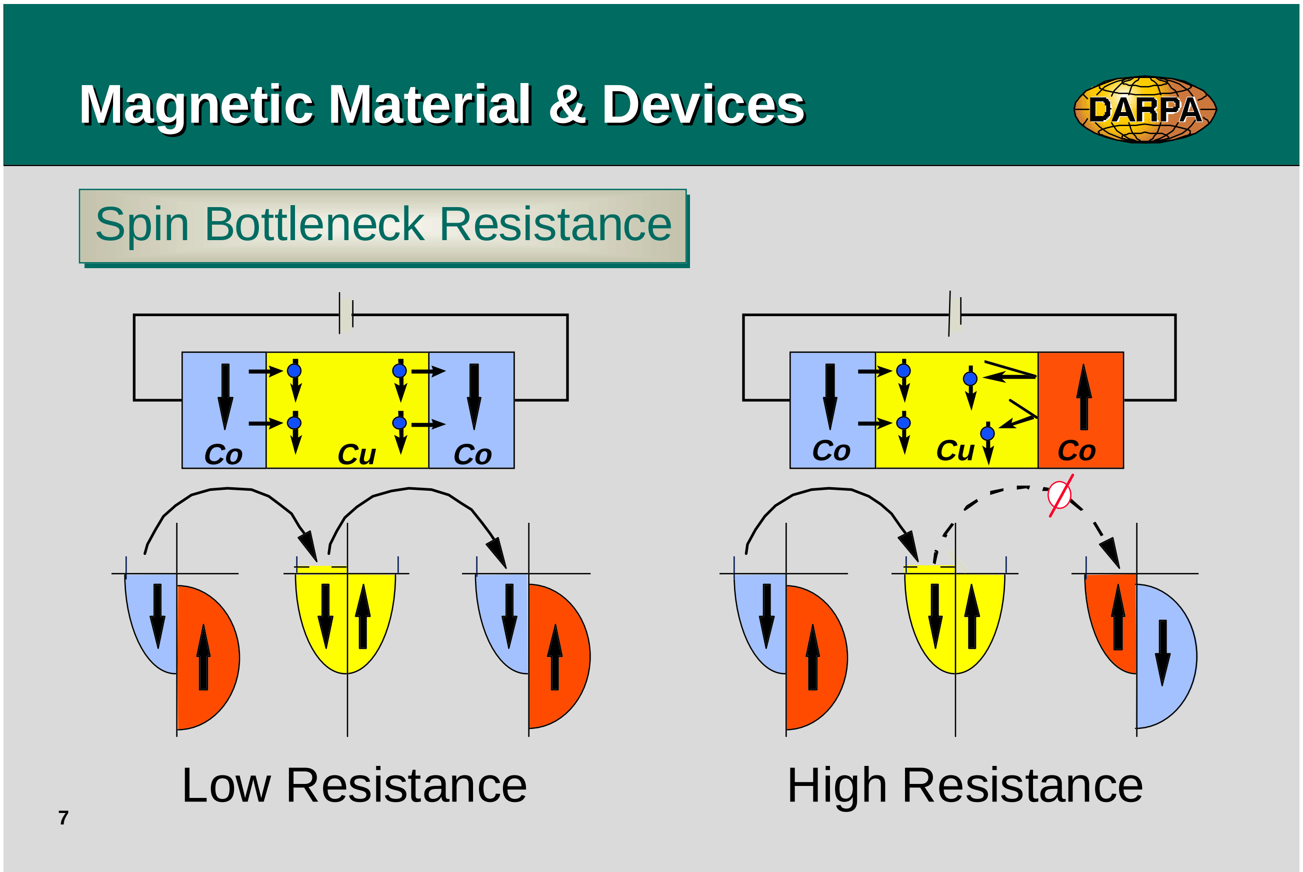
The magnetic materials and devices effort takes advantage of the magnetic spin degree of freedom of the electron. Conventional electronics only utilize the electron charge and the spin is irrelevant. Spin dependent properties, particularly transport properties, make possible a totally new paradigm of devices that we call spintronics. These devices can be used for non-volatile, radiation hard, very dense, very fast memory, very high sensitivity magnetic field sensors and non-volatile logic.



This slide demonstrates a very unique characteristic of magnetic metals. The electrons that can transport current in a metal are located very near to the Fermi level. In a non-magnetic, metal-like copper (on the left), the electrons at the Fermi level are composed of equal numbers of spin up and spin down electrons. In contrast, in a magnetic metal the electrons at the Fermi level are predominantly of one spin direction. In fact, in some magnetic metals like cobalt, the degree of spin polarization can approach 100%. This polarization of the electrons leads to some very unusual transport phenomenon.

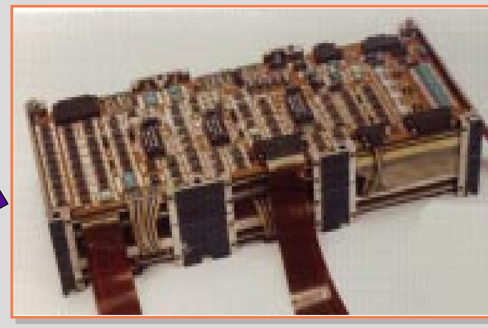


This slide demonstrates the effect called “giant magnetoresistance” in a sandwich structure consisting of two magnetic layers like cobalt surrounding a non-magnetic metal like copper. This device behaves like a polarizing filter. If the magnetic moments or spin directions of the magnetic metal are aligned, then the carriers from the magnetic metal can flow freely from one layer to the next and the resistance is low. If the spin directions are not aligned, then the electrons originating in one magnetic metal cannot enter the other one because there are very few empty states with that spin direction and they must scatter at the boundary. This leads to a significantly higher resistance. The resistance is a function of the angle between the two magnetic directions, being a minimum when they are aligned and a maximum when they are 180 degrees out of alignment. This effect is the basis of memory, sensor and logic devices. Depending on the selection of materials, the device can be hysteretic and thus would have “memory” or non-hysteretic and then be useful as a sensor. It is possible to replace the normal metal layer with an insulator and the transport becomes a tunneling process rather than a direct conduction process. The resistance changes in the tunneling device are larger, but the control on the insulator thickness becomes more critical.

Magnetic Material & Devices

SpinTronics: Enabling New Functionality for Defense Systems

- Develop non-volatile, radiation hard memory chip for space, missile and avionics applications (including jet engine control systems, missile and torpedo guidance and control, unmanned vehicles, and satellite)
  - Speed of SRAM (<3 ns)
  - Density of DRAM (4 Gbit)
  - Low power (0.1 - 0.01x)
  - Low cost (0.1x)
  - Infinitely cyclable



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This slide shows the significant potential for memory based on spintronics. Currently, radiation hard, non-volatile memory required for space and strategic applications is based on plated wire or core memory technologies, as illustrated. These technologies are large, heavy and expensive. Giant magneto-resistive devices can replace these memories and, in addition, provide performance that may approach or exceed the best volatile semiconducting memories. Thus, it is very possible that thin film magnetic memories can be built based on spintronics that have the density of DRAM, the speed of SRAM, at very low power and low cost.

Magnetic Material & Devices

- Develop high sensitivity, low cost magnetic sensors for:
  - Precision motion and rotation control for avionics
  - Perimeter defense
  - Detection of mines and buried ordnance

Integrated Magnetic Sensor

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Spintronics also enables the production of a host of magnetic field sensors and switches that can be integrated with the semiconducting control circuits on a very tiny chip. Magnetic sensors can be used as precision motion and rotation detectors for the control of mechanical systems in a variety of military vehicles. They can be made to have very high sensitivity to ferrous objects and this could be useful in perimeter defense, and finally they can be used to detect buried metallic and ferrous objects. The relative size of such a sensor is shown compared to a penny. This is a fully integrated sensor.

Frequency Agile Materials for Electronics (FAME)

Objective

Develop hybrid structures for frequency agile filters, antennas, oscillators and phase shifters utilizing the field dependent properties of ferroelectrics (ε(E)), ferrites (μ(H)) and other novel materials which can be tuned over at least an octave, exhibiting overall loss tangents less than 0.0005 (>10x over SOA).

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The Frequency Agile Materials for Electronics (FAME) program is focused on the development of structures whose properties can be tuned by an appropriate adjustment of the electric or magnetic field. Other novel structures like MEMS-type devices, whose properties can be modified to tune rf circuits, are also of interest in this program. The key to developing high performance components is minimizing the rf loss in the compounds. The goal of this program is to reduce the loss by an order of magnitude over the current state of the art. These materials will be demonstrated as frequency agile filters, oscillators and antennas.

Frequency Agile Materials for Electronics (FAME)

DARPA

Technology Drivers

- Electric and magnetic field tunable components
- MEMs capacitors
- Integration with standard integrated circuit fabrication
- Key: extremely low loss

Defense Applications

- High performance, secure, interference-free communications (SINCGARS)
- Miniaturized electronics for UAVs, missiles, & satellites

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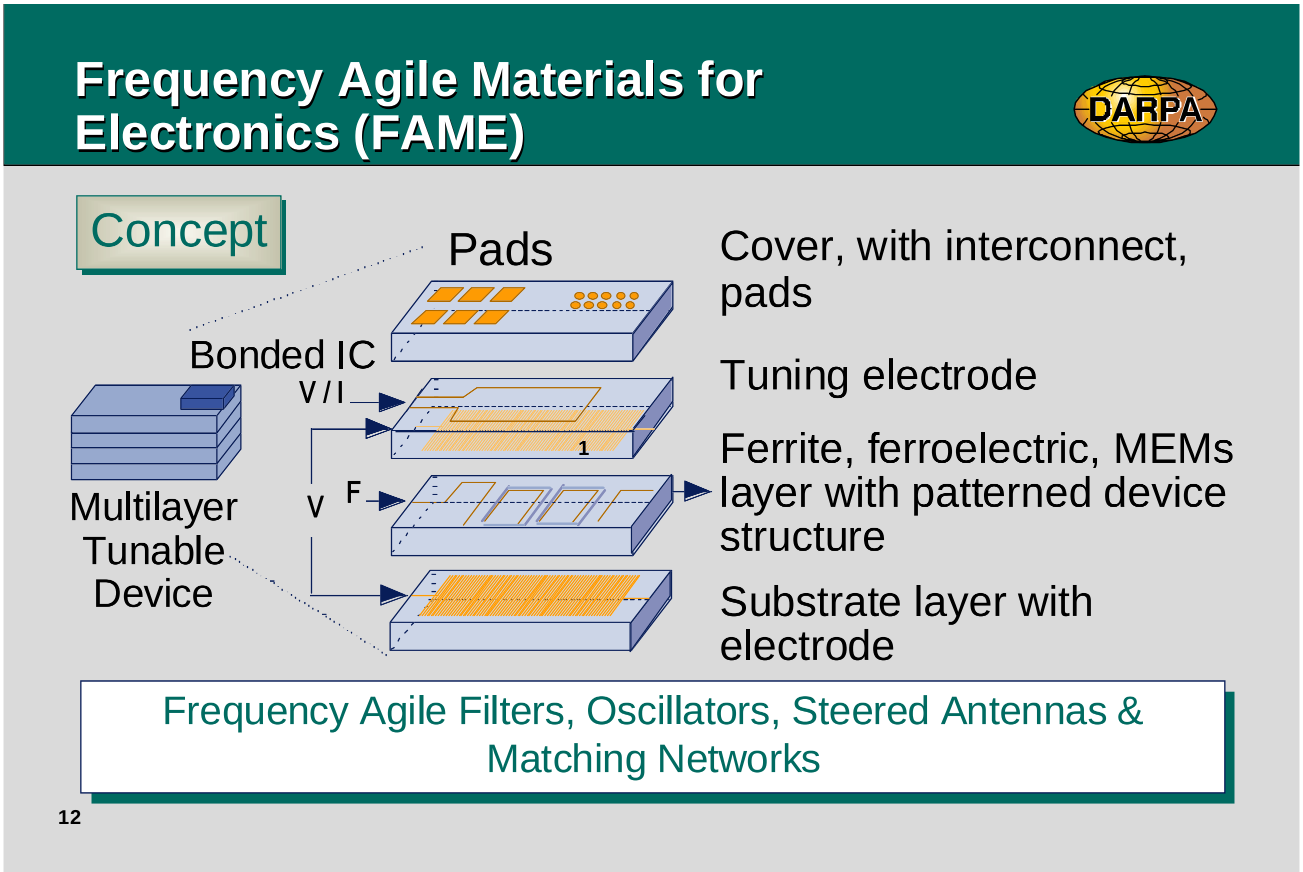
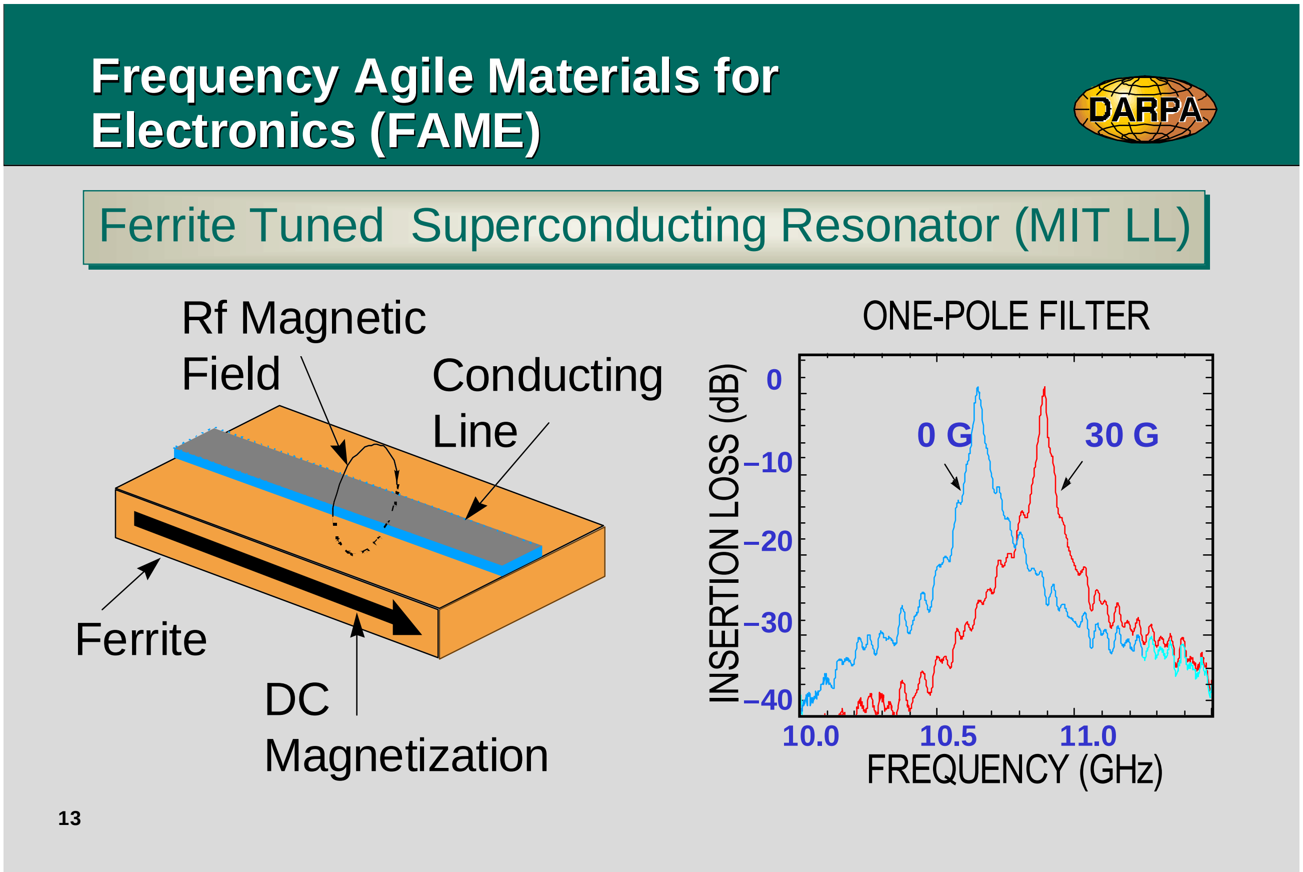
The FAME program is geared to the development of hybrid or integrated components that can be frequency tuned using electric or magnetic fields or quasi-mechanically with MEMS-type technology. These components should be integrable with standard semiconductor circuit processing and must maintain very low loss.

The applications of this technology are very wide ranging in defense systems. They vary from communications (like SINCGARS), to surveillance on a host of platforms, particularly those that have significant size, weight and power constraints.



This slide shows an artist's conception of a potential FAME device incorporating electrically, magnetically and mechanically tuned elements that can be integrated with conventional semiconducting elements. (The MEMS device is not explicitly shown.) These components could take the form of filters, oscillators and antenna matching networks that are both frequency or phase agile, and impedance matched.



This slide depicts a device that has been demonstrated by MIT Lincoln Laboratories under FAME funding. The resonant frequency of a superconducting strip (single pole resonator) on a ferrite substrate can be continuously tuned from approximately 10.5 to 11 GHz by applying magnetic fields from 0-30 gauss. The quality factor of the resonator stayed above 3000 during the tuning.

Advanced Thermoelectric Materials

Goals

- Create new classes of thermoelectric devices for cooling and power generation by
  - Synthesizing and measuring novel thermoelectric materials
    - Bulk, thin film, mesoporous
  - Synthesizing and measuring Novel Structures
    - Superlattices, Quantum Wells,Quantum Wires, Quantum Dots, and Graded Layers
- Offer at least an order of magnitude enhancement in performance making these devices competitive with phase change systems (ZT>3)

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The Advanced Thermoelectric Materials program hopes to discover and exploit new thermoelectric materials with significantly improved properties. In particular, the figure of merit, ZT, for thermoelectrics has been rather stagnant at a value of about one for many years, and few efforts have been focused on this class of materials. New combinatorial synthesis methods, the ability to fabricate new ternary and quaternary compounds, predictions about the properties of very novel structures and advances in computation have created an opportunity for real progress in this area. The goal of this program is a figure of merit (ZT) of three or more, which would make these devices very competitive with conventional phase change systems, albeit with the very desirable attributes, described in the next slide.

Advanced Thermoelectric Materials

DARPA

Benefits of TE Cooling/Power Generation

- High reliability (>250,000 hrs.)
- Silent
- No vibrations
- Small
- Lightweight
- Decreased life cycle costs
- Very efficient at low cooling power
- No compressed gases or chemicals
- Environmentally “green”

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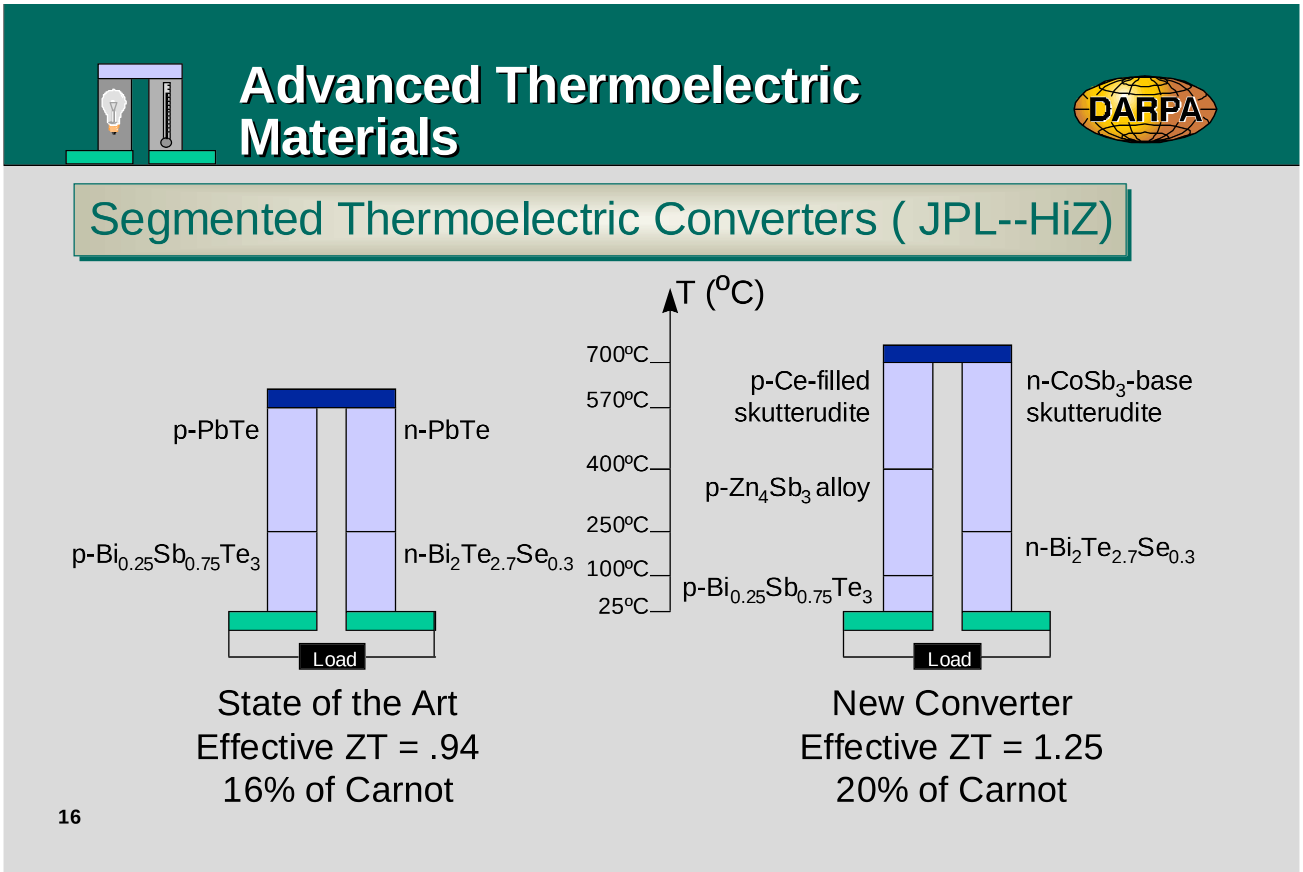
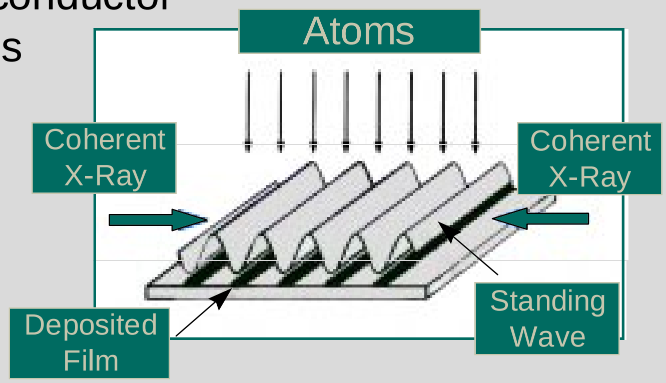
This slide details the attributes of thermoelectric devices for cooling and power generation. It is clear from this list that even small advances in the efficiency of thermoelectric devices offer large benefits and even a figure of merit (ZT) of 1.5 or greater would create significant markets for these materials and devices. In fact, a ZT of 1.5 would make thermoelectric coolers highly competitive for cooling submarines.



This slide shows some recent results by the Jet Propulsion Laboratory on a class of semiconductors called skutterudites. These newly studied compounds have a figure of merit, measured above 300C, that exceeds one. In fact, these materials should make the recovery of waste heat from internal combustion engines quite attractive. As you can see, a segmented thermoelectric device utilizing the new materials as the high temperature segment would improve the performance of this state-of-the-art converter from 16% to 20%.

Crystal Growth

- Develop techniques for growing device-quality, thin single-crystal films on amorphous and/or non-lattice-matched substrates for three-dimensional integration of semiconductor devices and devices composed of multiple materials.



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The Crystal Growth effort, managed by Bill Coblenz, has the goal of developing innovative techniques for forming an atomic resolution template on an amorphous or polycrystalline substrate using x-rays, as illustrated, or other novel methods that can provide a means for facilitating the growth of device quality single crystalline semiconductor films. This effort has a BAA open until the middle of November

Electromagnetic Materials

Summary

Over the past few years DARPA has initiated several new thrusts in materials that are important for electromagnetics. It will be an area for future expansion as well.

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